Laboratory investigation on the mechanics of soft-rigid soil mixtures

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Abstract. Rubber particles derived from recycled tyres are used as a practical materials in construction industry, including geotechnical systems. Drained triaxial compression tests are conducted to investigate the mechanical behavior of Leighton Buzzard and rubber particles mixtures, bot materials with identical particle size distributions. Distribution of constituents throughout the sample is also explored through x-ray CT testing.

Keywords: laboratory, sand, tyres, triaxial test

1. Introduction

The number of scrap tyres is increasing rapidly in both developed and developing countries due to the steady rise in the number of vehicles. As a consequence, the accumulation of used tyres is gradually becoming a real societal problem, equally from an economic and environmental points of view. Recent research showed that this material can be considered as an alternative for some conventional materials in construction industries. As far as geotechnical systems are concerned, the use of the scrap tyres or tyre chips for backfilling can be an attractive solution that would provide lighter weights on the retaining structures compared to traditional backfilling materials [1], [2]. The tyre shreds apparently produce less horizontal pressure than conventional granular backfills [3]. The possibility for the inclusion of tyres or rubber chips derivatives in other geotechnical applications like soil prevention erosion [4], slope stabilization and highway embankments [5, 6], road constructions [6, 7] and seismic isolation of foundations [8] is under attention. However, before extensive implementation, further research is still required in order to understand the behaviour of the soil/tyre chip composite mixtures, including internal interaction mechanisms resulted from the combination of two particular materials, one soft, tyre rubber, and one rigid, granular soil. Insight into the underlying particle-level mechanisms and their role on the macroscale behaviour for either fine rubber particles mixed with coarse sand grains or coarse soft particles with fine rigid sand grains has been explored [9, 10]. The quality of soft-rigid soil mixtures produced by normal mixing and depositional procedures, including the mitigation of particle segregation phenomena represent a challenge for their implementation at real scale.

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2. Aims and Objectives

In this paper, laboratory experimental results are presented on sand-tyre rubber chips mixtures in view of exploring the role of the soft particles on their mechanical behaviour. The main idea here is the use of rigid and soft particle constituents with identical particle size distributions (PSD), avoiding the contrast effects of the particle size scales. Therefore, the analysis of the rigid/soft mixture is mainly focused on the effect of the proportions of the mixture constituents. When testing rubber/sand composites in the laboratory, one of the main concerns is the segregation of particles that can occur in the fabrication process of the samples. A non-destructive method for the assessment of the uniformity of the distribution of rubber particles throughout the sample is explored. The mechanical behaviour of the sand/rubber mixture has been investigated in triaxial compression testing under drained conditions and various confining stresses.

3. Materials

Leighton Buzzard fraction A sand has been chosen in this research. This is a natural, silica sand characterized as a coarse material. Following a long and tedious process that involved market investigation, individual assessment of rubber chip samples sent by various suppliers, sieving and sorting of the particles, an equivalent rubber type material has been created to match the particle size distribution (PSD) of the Leighton Buzzard sand (Figure 1). Rubber material resulted from the shredding process of used lorry tyres and it consists of polymer, acetone, carbon black, ash and sulphur.

Various index properties of the materials are given in Table 1. Figure 2 shows a series of individual sand and rubber particles for some visual appreciation of the particle shapes.

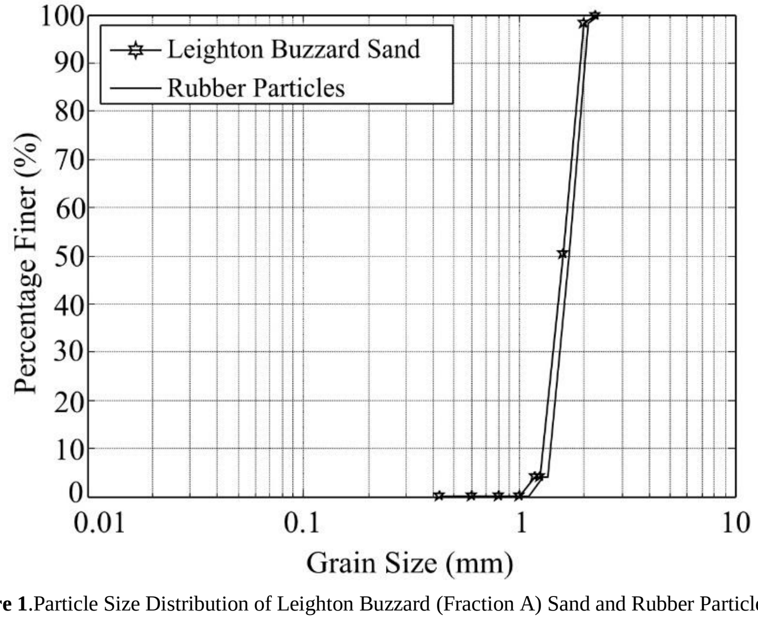

Figure 1.Particle Size Distribution of Leighton Buzzard (Fraction A) Sand and Rubber Particles

Table 1. Index Properties of Materials

Material Properties	Rubber Particles	Leighton Buzzard Sand
Specific Gravity	1.04	2.65
Minimum Void Ratio (e_{min})	-	0.55
Maximum Void Ratio (e_{max})	-	0.83
Mean Grain Size (D_{50} (mm))	1.8	1.8
Coefficient of uniformity (C_u)*	1.27	1.27
Coefficient of Curvature (C_g)**	1.12	1.12

*$C_u=D_{60}/D_{10}$ **$Cg= (D_{30}*D_{30})/ (D10*D_{60})$

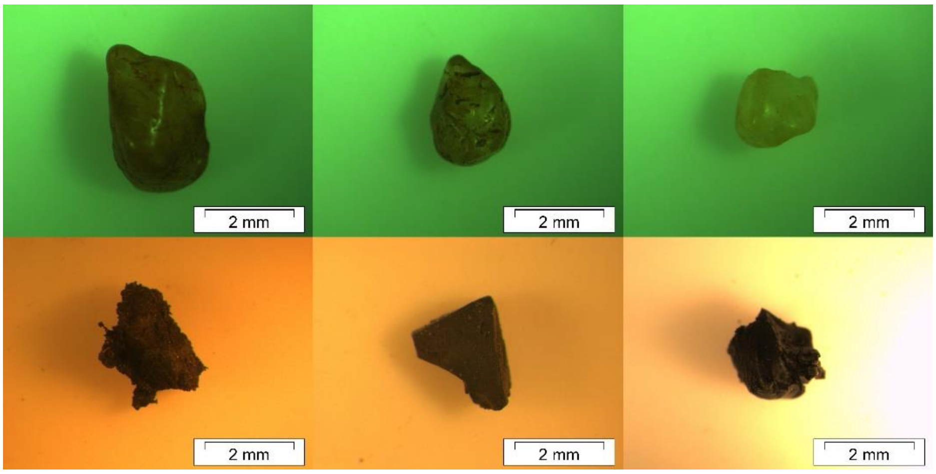

Figure 2. Individual particles of Leighton Buzzard Sand (top row) and Rubber Particles (bottom row)

4. Sample Fabrication

There are different ways to create rubber-sand samples in laboratory but, in general, the fabrication process invariably consists of mixing, deposition and compaction stages. Although water content is normally used for mixing sand and shredded rubber tyre chips [11], the mixing process can also be completed in dry conditions [12]. The deposition of the composite mixture is made either in one layer or several successive layers by using a funnel or by spooning of the mixture in small quantities and zero drop deposition height. The compaction is completed by tamping [12], tapping [13, 14] or vibration [3]. However, laboratory samples of rubber-sand mixtures are most commonly prepared using a moist tamping (MT) technique. While this technique could be much more effective in discouraging segregation of the constituents of the composite, providing good control of sample density and homogeneous distribution of rubber, it produces a soil-rubber fabric which corresponds to that obtained in rolled-compacted construction fills.

4.1. Distribution of tyre chips

Different fabrication methods (dry deposition and layers compaction, dry deposition and vibration, moist tamping) have been explored in this research. However, the results presented here will be limited to dry deposition of the mixture followed by light compaction by a circular tamper (half sample diameter) and vibration. The samples with a rubber fraction F_R= 30% were prepared in a transparent Perspex tube of 70mm diameter and 70mm height as shown in figure 3. The rubber fraction, F_R, is defined by the following relationship:

$$F_R = \frac{V_{Rubber\ \ particles}}{V_{Rubber\ \ Particles}\ +V_{Sand\ \ Particles}} \tag{1}$$

where the letter 'V' stands for volume.

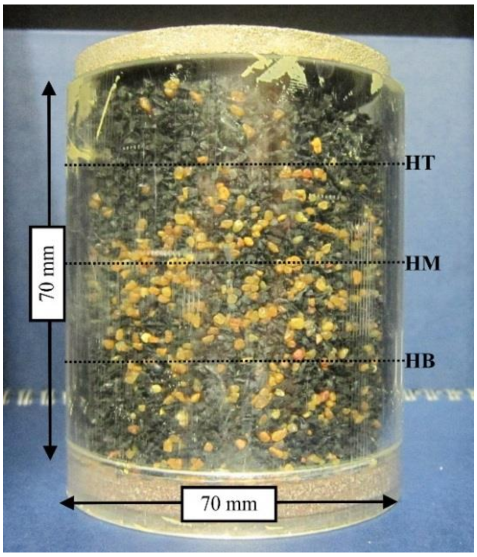

Figure 3.Sample in Perspex tube

The assessment of tyre chips distribution was conducted through 3D x-ray CT testing. X-ray tomography provide 2D high resolution images with a resolution of 50µm/px. The particles of sand with high density will appear in the images in a grey colour, lighter than and clearly distinguished from the rubber particles. The darkest zones represent the voids (Figure 4a).

As it is shown in figure 3, the sample was divided in three horizontal sections: HT, top side of the sample, located at 2cm from the top; HM, middle; and HB, bottom side, located at 2cm from the bottom. Each horizontal section was further divided in four square areas, as displayed in Figure 4. At each HT, HM and HB level, 40 successive horizontal images representing an overall slice of 2mm thickness (approximate D_{50}) – 20 above and 20 below each level – were selected and each image was analysed separately using Matlab software to estimate the sand area (A_S) and rubber area (A_R) with respect to the total areas (A_T) of the analysed sub-section. As an example, Figure 4b shows the sand particles (white) in four horizontal sub-sections, while the black zones represent rubber and voids. Similarly, images with rubber selected particles can be generated and rubber area A_R estimated. In a first approximation, for one section, we can assume that the F_R ratio can be given by $n_1/(n_1+n_2)$, where $n_1= A_R/A_T$ and $n_2=A_S/A_T$. The F_R ratio for each level and sub-section, is then obtained by averaging of F_R ratios of all 40 sub-sections, above and below that level. The obtained F_R values for HT, HM, and HB levels are given in the Tables 2, 3 and 4 respectively. It can be observed that the distribution of the constituents at one level is not particularly homogenous, with F_R values within 10% range. The F_R average of rubber fraction for each level reveals the existence of some degree of segregation between the constituents with higher rubber content on top of the sample than at the bottom. The F_R average decreases from 34% on top of the sample to 24% in the middle and 20% at the bottom. The analysis of various images also shows that near the vertical sample boundary, over two to three times D_{50} thickness area, the concentration of rubber particles is much higher than the sand. In addition, it also appears that some rubber particles tend to agglomerate and create visible rubber clusters.

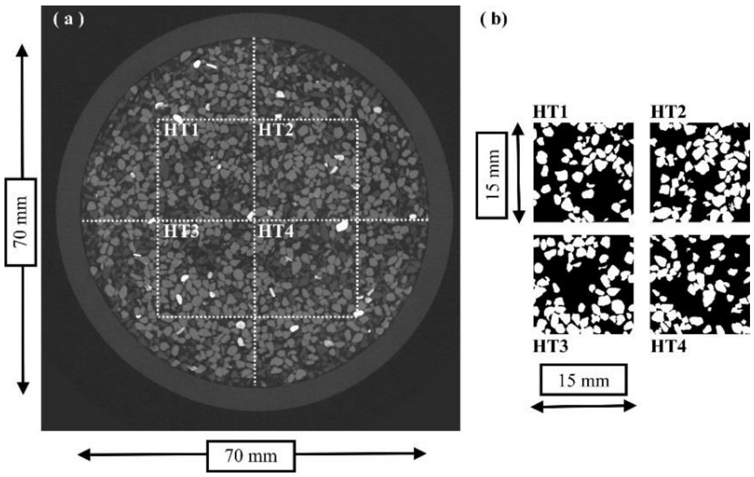

Figure 4. (a) Horizontal top section of the sample (HT); (b) Equivalent HT1 to HT4 sub-sections for image analysis with sand particles (white) and the black zones representing rubber and voids

Table 2.Area Ratios for Top horizontal sections

Element No.	**A_S/A_T**	**A_R/A_T**	**F_R**	**F_R(average)**
HT1	0.37	0.23	0.38	
HT2	0.46	0.17	0.27	0.34
HT3	0.41	0.19	0.32	
HT4	0.35	0.24	0.40	

Table 3.Area Ratios for Middle horizontal sections

Element No.	**A_S/A_T**	**A_R/A_T**	**F_R**	**F_R(average)**
HM1	0.42	0.15	0.26	
HM2	0.46	0.11	0.20	0.24
HM3	0.49	0.14	0.22	
HM4	0.42	0.16	0.28	

Table 4.Area Ratios for horizontal sections

Element No.	A_S/A_T	A_R/A_T	F_R	F_R(average)
HB1	0.46	0.10	0.18	
HB2	0.43	0.13	0.23	0.20
HB3	0.49	0.07	0.13	
HB4	0.50	0.16	0.25	

5. Triaxial Compression Tests on Sand-Rubber Samples

Cylindrical samples with 70mm in diameter and 70mm in height were made with moist tamping method. Different F_R values of 0%, 5%, 10%, 20%, 30%, 50% and 100% have been considered, while the sample fabrication void ratio of 0.64 has been kept identical for all samples.

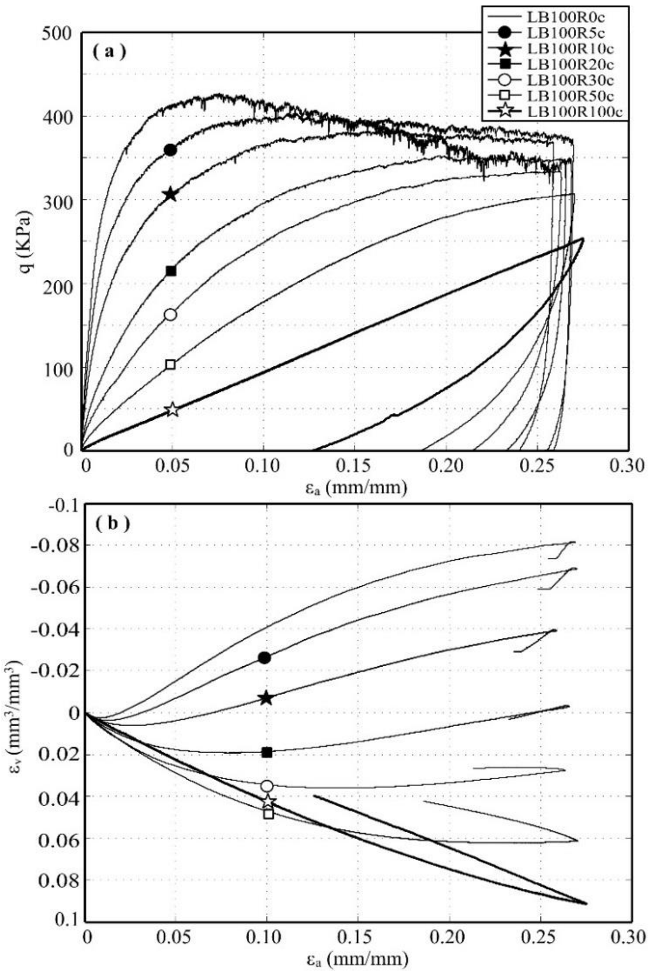

Figure 5.Triaxial Compression Tests on Leighton Buzzard/Rubber Mixture: (a) Deviator Stress-Axial Strain; (b) Volumetric Strain-Axial Strain

The triaxial tests were performed on saturated samples and that allowed the measurement of the sample volume change. Extensive research has shown that a sample aspect ratio of 1 preserves better the sample uniformity (cylindrical deformation) at very large strains and delays the manifestation of localisation when enlarged lubricated top and bottom sample platen ends are used. Therefore, enlarged top and bottom platens as well as anti-frictional systems have been used. Samples with different rubber fraction were tested in drained triaxial compression under different confining pressures of 50kPa, 100kPa and 200kPa. However, in this paper only the results at 100kPa confining pressure are presented. Deviator stress and volumetric strain of the samples with axial strain are shown in figure 5. The results present the well expected behaviour of dense sand which are pronounced peak deviator stress followed by softening towards a critical state and highly dilative volumetric behaviour. Linear stress-strain response and contractive volumetric behaviour of rubber sample are also shown in this figure which is consistent with previous works [3]. It is clearly shown that adding rubber to sand generates an intermediate response. Although the strength of the rubber-sand mixtures decreases, the strain corresponding to the peak deviator stress increases. The volumetric behaviour for 20%, 30% and 50% rubber fractions is also closer to the pure rubber sample behaviour. The volumetric behavior of samples with F_R>30% are fully contractive compared to the samples with less rubber fractions. On the other hand the volumetric behaviour of 5% and 10% mixtures is closer to pure sand sample. These results are also consistent with some previous studies [12]. The variation of the mobilized angle of friction for all the tests under different confining pressures with the rubber fraction is presented in Figure 6.

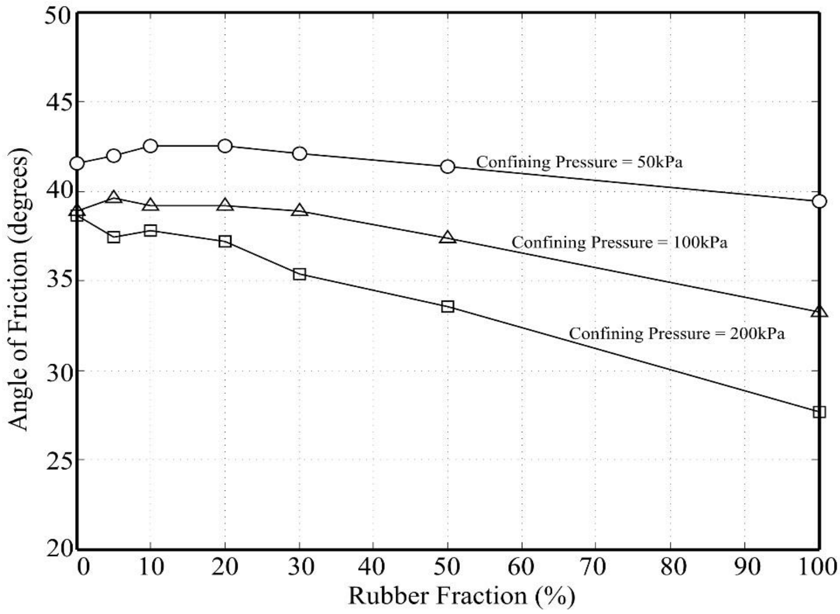

Figure 6.Variation of mobilized angle of friction under different confining pressures for all the tests

6. Conclusion

Leighton Buzzard sand and rubber particles mixtures were studied in this paper. The rubber particles, resulted from shredding process of used scrap tyres, were chosen with the same particle size distribution of Leighton buzzard sand. Different sample fabrication methods were considered to analyse the homogeneity of the composite and possibly detect signs of segregation between the constituents. Samples fabricated by dry deposition and light compaction and vibration, showed some degree of non-uniformity and apparent segregation with a higher concentration of rubber particles on the top of the sample. Samples with different rubber fractions of 0 to 100% were tested in drained triaxial condition under different confining pressures. As expected, rubber particles have significant effects on both stress-strain and volumetric strain of the mixtures. Further investigation using a finer soil and finer rubber particles is in progress.

References

[1] D.N. Humphrey and W.P. Manion. Properties of tire chips for lightweight fill. in *Grouting, Soil Improvement and Geosynthetics*. 1992. ASCE.

[2] V.K. Garga and V. O'shaughnessy, Tire-reinforced earthfill. Part 1: Construction of a test fill, performance, and retaining wall design. Canadian Geotechnical Journal. **37**(1) (2000): p. 75-96.

[3] J. Lee, R. Salgado, A. Bernal, and C. Lovell, Shredded tires and rubber-sand as lightweight backfill. Journal of Geotechnical and Geoenvironmental Engineering. **125**(2) (1999): p. 132-141.

[4] P.S. Poh and B.B. Broms, Slope stabilization using old rubber tires and geotextiles. Journal of performance of constructed facilities. **9**(1) (1995): p. 76-79.

[5] P.J. Bosscher, T.B. Edil, and S. Kuraoka, Design of highway embankments using tire chips. Journal of geotechnical and geoenvironmental engineering. **123**(4) (1997): p. 295-304.

[6] D.E. Nightingale and W.P. Green, An unresolved riddle: Tire chips, two roadbeds, and spontaneous reactions. ASTM SPECIAL TECHNICAL PUBLICATION. **1275** (1997): p. 265-285.

[7] T.C. Heimdahl and A. Drescher, Elastic anisotropy of tire shreds. Journal of geotechnical and geoenvironmental engineering. **125**(5) (1999): p. 383-389.

[8] Y. Tsompanakis. , P.N. Psarrapolous, and V. Drosos, Low-cost seismic base isolation using recycled tires cush-ions. 2009, Technical University of Crete.

[9] J.S. Lee, J. Dodds, and J.C. Santamarina, Behavior of rigid-soft particle mixtures. Journal of materials in civil engineering. **19**(2) (2007): p. 179-184.

[10] H.K. Kim and J.C. Santamarina, Sand-rubber mixtures (large rubber chips). Canadian Geotechnical Journal. **45**(10) (2008): p. 1457-1466.

[11] S. Youwai and D.T. Bergado, Strength and deformation characteristics of shredded rubber tire sand mixtures. Canadian Geotechnical Journal. **40**(2) (2003): p. 254-264.

[12] J.G. Zornberg, A.R. Cabral, and C. Viratjandr, Behaviour of tire shred sand mixtures. Canadian Geotechnical Journal. **41**(2) (2004): p. 227-241.